

An overview on Brazilian Energy Market

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Abstract. Brazil is a major player in the global energy market, with the seventh largest electricity generation capacity in the world. The country's energy sector is characterized by a strong reliance on hydropower, but there is also a growing trend towards renewable energy sources such as wind and solar power. This article makes a general overview on Brazilian energy market, focusing on legal framework, regulatory authorities and transport and distribution system both on electricity and oil and gas sectors. It is also presented the today market situation.

Finally, the article concentrates on energy produced from renewable sources and make a parallel on renewable energy market comparing the situation in Brazil, India and China.

Keywords: Brazil, energy market, energy market, energy mix, renewable energy

Introduction

Brazil with a population of about 217 million citizens is ranked as 6th largest country. Its population is relatively young and there are no religious and sectarian problems.

As political organization, it is a federal state comprising 27 states and more then 5.000 municipalities.

Country experienced a steady economic development in last decade, being presently the ninth -largest economy in the world.

Energy sector place Brazil among top 14 countries referring to sustainability.

The electricity production mix is dominated by hydropower plants which produce about 80 % of the electricity. The energy produced from renewable increased its share in last decade.

Electricity transmission and distribution system have efficiency problems, experiencing a transport and distribution losses of about 16 % . The grid also have difficulties in integrating the energy produced from new renewables sources.

According data published by www.enerdata.net, Brazil had on 2022 an electricity consumption per inhabitant of about 1.4 toe, which place it among semi-industrialized countries, comparing with Europe which have capita electricity consumption of about 2.9 toe.

Electricity consumption increased with about 3.8% per year in 2001-2015. Between 2015 - 2022 total electricity consumption increased with about 1.5% per year reaching to 570 TWh. In 2022 about 99.95% of the households were electrified.

The oil production experienced an increase of about 4.4 % every year starting with 2013, reaching in 2022 at 157Mt. Brazil is also a net oil exporter, its exports increasing with about 20% per year between 2013-2020, amounting at 55Mt in 2022. Oil consumption is dominated by transport sector which use about 62%, followed by residential sector with 12%, non -energy usage sector with 11 % and industry sector with 10%.

The gas consumption increases with about 12% per year between 1999-2014. Between 2014-2020 the consumption decreases with about 21% reaching to 34.5bcm. The decrease continues also in 2022, being 32bcm.

Coal consumption decreased about 5% per year between 2015-2020. It increased in 2021 reaching 29Mt but in 2022 decreased about 25% to 21.6Mt.

Literature review

Adilson de Oliveira, in “Energy Security in South America- Role of Brazil”, published in 2010 present Brazil energy markets, its resources, possibilities and obstacles for power plants integration, environmental issues and the regulation for private investment.

Under UK PRACTICAL LAW -Thomson Reuters, Schmidt et al. (2021) in “Electricity regulation in Brazil: overview” published in 2021, make an overview on electricity regulation in Brazil. It presented government policy and recent trends. It also analyzed the regulatory framework and the regulatory authorities and their responsibilities.

The entire electricity chain is presented starting from generation, passing to transmission and distribution and ends with supply. The foreign investments, tariffs construction and renewable sources are overviewed.

Faveret Lampert Advogados - Ivan Lafayette Bandeira Londres, José Roberto Faveret Cavalcanti and Lucas Carvalho de Souza in “A general introduction to oil and gas law in Brazil” published in 2021 present the legal framework of Brazilian oil and gas regulation starting with domestic legislation, regulatory laws and organization and international treaties where Brazil acceded.

Saragoça et al. (2023) “Oil and gas Regulation- Brazil” published under International Comparative Legal Guides -18th edition, make an overview of natural gas and oil jurisdiction, organizational of the regulatory framework and regulatory authorities, production, transmission and distribution facilities and networks. Import and export facilities and regulation for oil LNG is also presented. There are also stated the foreign investment procedures and legislation as well as dispute solving.

International Trade Administration “Country commercial guides / Brazil energy” published in 2023 make a short presentation of Brazilian energy sector, with short description of oil and gas sector, nuclear sector and electric power system with its generation, transmission, distribution components. The renewables sources are also presented.

International Energy Agency “Latin America Energy Outlook -Overview Brazil,” published in 2023 represent a short presentation based on data starting with 2010 to 2021 and the prediction until 2050 of country’s most important energy indicators like primary energy supply, trade of main energy and non-energy products, recent policy developments, major infrastructure project, energy consumption and electricity and fuel generation and demand.

International Renewable Energy Agency in “Energy Profile – Brazil” published in 2023 present total energy supply 2015/2020 and the renewables share, renewable energy mix 2016-2021 and indicators of renewable resource potential.

Brazil energy market legislation

The theoretical examination of Brazil's energy market involves analyzing the legal frameworks of the energy market, energy production, distribution and consumption within the country. This analysis considers Brazil's unique position in the global energy landscape, characterized by a

substantial reliance on renewable energy sources, alongside a significant oil and gas sector. The discussion encompasses key theoretical concepts such as energy security, sustainability, market liberalization, and the energy transition.

Electricity market

In Brazil the energy sector, because of his importance in developing the country it is supervised by federal government which have establish that according to the law the sector can be exploited directly or indirectly by known possibilities (authorization, concession or permission).

The Concession Law (no. 8,986/1995) and the Power Concession Law (no. 9,074/1995) establish the rules for electricity market putting accent to transparency and competitive bidding process in energy sector. These new legal approaches lead to creation of more competitive market which allow to some consumers which fulfill legal requirements to buy energy directly from suppliers.

National Electric Energy Agency (ANEEL) was created by the law no. 9,427/1996 with the role of regulatory and supervision authority. In 1998 the law no. 9,648 was adopted in order to create the frame for wholesale electricity market.

Now, the power sector is composed of two markets:

- The regulated power market composed mainly of distribution companies and captive consumers, whose commercial relationship is fully regulated by ANEEL. The distribution companies can charge and receive a determined rate (tariff) for the power they supply. They must, however, acquire their entire power demand through power auctions organized and supervised by ANEEL.
- The free power markets. Free power consumers, power generators and trading companies are the main agents in this market. These agents are free to negotiate their own power volumes and prices.

(Guilherme Schmidt et. al, 2021, *Electricity regulation in Brazil: overview view on April 2023 on <https://uk.practicallaw.thomsonreuters.com>*)

Government policy objectives

As the sole regulatory and supervision authority, ANEEL assure the development of the sector pursuing its main objectives establish by law:

- regulatory framework to stimulate efficiency and sustainability
- quality electricity services with correct and competitive prices
- consistent and simplified regulation
- promotion of technological innovation and energy efficiency.
- auction process and management of concessions and authorizations granted by the ANEEL, with focus on contractual and regulatory compliance, and others

Oil and gas market

The Brazilian oil and gas sector is regulated by general provisions of the Brazilian Constitution, as well as by a number of different federal laws, and ordinances and resolutions enacted by ANP.

According Brazilian Constitution oil and gas reserves onshore or offshore belong to the Brazilian State. Constitutional Amendment no.9 /1995 allow private and state-owned companies explore and product oil and gas, as a consequence of partial lifting of state monopoly.

Law no. 9,478/1997 was adopted in order to end Petrobras' monopoly. Was created the National Council for Energy Policy (CNPE) chaired by Minister of Mine and Energy with main role of prepare energy policies and guidelines.

As market regulatory authority was formed Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP) who overlooks also to proceedings for concessions rights for gas and oil exploration and production (Faveret Lampert Advogados, 2021, A general introduction to oil and gas law in Brazil, view on April 2023 on <https://www.lexology.com>)

Regulatory authorities

Electricity market

The regulatory aspects considered to evaluate power quality service directly affect the results of power systems performance. Among the inherent characteristics, it can be verified whether the service is public or private, how many utilities exist, and the influence of international companies. In addition to these points, it is worth highlighting issues related to the existence of service quality metrics, the level of consumer satisfaction, the amount of investments in the network, the profit achieved by the utilities, initiatives aimed at research, and the dissemination of data on the performance of distributors. The search for this information aims to obtain an overview of the electricity distribution sector in South America, to highlight similarities, differences, and peculiarities between the analyzed countries, focusing on the quality of electricity (Delavechia et al, 2023).

Ministry of Mines and Energy (MME) is responsible for formulating and implementing national policies on the energy sector. Currently, the MME is responsible for granting concessions and permissions to exploit electric power services and facilities.

ANEEL. This is a special independent body linked to the MME. It has technical and political autonomy to regulate, supervise and monitor activities related to the energy sector.

National Energy Policy Council (*Conselho Nacional de Política de Energia*) (CNPE) is a governmental body that advises the President. Its main function is to suggest policies and guidelines to promote the sensible use of national energy resources to maintain the lowest possible rates for consumers.

Monitoring Committee for the Electric Sector which monitors the continuity and security of electricity, natural gas and oil supply, identifying risks and developing proposals to predict and solve risk situations.

Operator of the National Electricity System (ONS), a non-profit private entity that manages the national interconnected transmission system (*Sistema Interligado Nacional*) (SIN). The ONS is made up of all the agents connected to the basic grid, and its main functions are:

- planning and programming the operation and centralized dispatch of power generation, envisaging the optimal operation of the SIN;
- supervising and coordinating the operation centers of the SIN;
- preparing and presenting to the MME studies on the expansion and reinforcement of transmission systems; and
- preparing and presenting new rules for the operation of the basic grid for the approval of ANEEL.

Energy Research Company (EPE) is a state-owned company that conducts studies and research to provide technical support for presenting long-term power planning in Brazil. It also identifies potential energy sources for national development and plays a role in the preparation of studies for power auctions.

Electric Power Commercialization Chamber (CCEE) is a non-profit private entity regulated and supervised by ANEEL. It is responsible for registering and processing the volume of all the energy contracted in the electricity power market. Short-term power transactions are settled financially at the CCEE. Long-term power transactions are also registered with CCEE, but are settled financially directly by the parties. The CCEE is also responsible for calculating the clearance price for the difference in the contracted volumes in the short-term market, as well as being responsible for conducting auctions for the sale of energy to distribution companies in the regulated market.

(Guilherme Schmidt et al., 2021, Electricity regulation in Brazil: overview view on April 2023 on <https://uk.practicallaw.thomsonreuters.com>)

Oil and gas market

Oil and gas exploration and production activities must also comply with environmental laws and regulations created by the national environmental agency (IBAMA).

Ministry of Mines and Energy (MME) is mainly responsible for planning the use of oil and natural gas. MME, after consulting with Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP), proposes to **National Energy Policy Council (CNPE)** the definition of the areas that will be subject to a concession agreement or production sharing agreement (PSA) regime, and the technical and economic parameters for the PSA. MME also approves the drafts of the bid documents and the PSA prepared by ANP.

National Energy Policy Council (CNPE) has the main purpose of fostering the rational use of the nation's energy resources, ensuring the proper functioning of the national fuels inventory system, reviewing energy matrixes for different regions of Brazil and establishing guidelines. It is responsible for authorizing Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP) to offer blocks under the concession regime and the PSA regime.

Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP) is the national regulator of the oil, gas and biofuels industry, and is in charge of regulating, contracting and supervising economic activities related to the oil, natural gas and biofuels industry, as well as establishing technical standards for various related activities. ANP is also responsible for supervising compliance with safety standards and its regulations.

National Environmental Agency (IBAMA) is responsible for environmental regulations regarding upstream offshore activities. For onshore activities, other state and local environmental agencies may also have the power to regulate upstream activities.

The Brazilian Maritime Transportation Agency (ANTAQ) is responsible for regulating and supervising the maritime transportation of oil as well as maritime support activities. Only Brazilian navigation companies, duly authorized by ANTAQ and ANP, may perform maritime transportation and support activities within the country.

The Brazilian navy has multiple roles in offshore exploration and production. In addition to technical inspection and entry control for any vessel or platform, it has jurisdiction over any incidents that take place on Brazilian waters. It is also responsible for maintaining the registry of maritime property, such as vessels. (Faveret Lampert Advogados, 2021, A general introduction to oil and gas law in Brazil, view on April 2023 on <https://www.lexology.com>)

Energy sector organization

Electric Power Systems

Brazil is the largest electricity market in Latin America and has the seventh largest electricity generation capacity in the world. Installed capacity reached 181.6 GW in 2021, a 3.9% increase from 2020, with remarkable growth from wind power (21.2%) and solar power (40.9%). Brazil generates and distributes electricity to over 85 million residential, commercial, and industrial consumers, more than the power produced by all other South American countries combined. Investment into the Brazilian electricity sector is expected to reach \$94 billion by 2029, including utility-scale generation, distributed generation, and transmission projects.

Generation

Brazil registered a total installed capacity of 181.6 GW in 2021, 84% of which is from renewable sources, with hydropower being the largest source. Thermal power (coal, gas, oil, and nuclear) represents 16% of the Brazilian electricity matrix. According to the Energy Planning Agency (EPE), Brazil is expected to add nearly 37 GW of power generation by 2030. Investments in utility-scale power generation are estimated to reach \$62 billion by 2029, while distributed generation should see \$10 billion in investment over the same period. Distributed generation increased 84% in 2021, primarily from solar power.

Transmission

Brazil has a country-wide interconnected grid of over 100,000 miles of high voltage transmission lines. By 2030, an additional 25,000 miles will expand the grid significantly. Total investments in the power transmission sector over the same period are projected to reach \$18 billion, of which \$13 billion will be in transmission lines and \$5 billion in substations.

Distribution

Brazil has 102 power distribution companies. Private firms owned by foreign investors prevail in this segment. Large international companies operating in this market include Spanish Iberdrola and Italian ENEL. This segment sees annual investment of around \$2.2 billion per year, 69% of which is in expansion, 19% in improvement and 12% in renewal of distribution networks. (<https://www.trade.gov>, 2023- Brazil Commercial Guide)

Oil and gas system

Transport of oil and gas are done through pipe lines.

The Petroleum law and ANP resolution nr.52/2015 stipulates that all construction, extension and operation of the transport pipelines must be authorized in advance.

Regarding the transport of natural gas, according the existing law it can be done by Brazilian companies either by concession (organized in bidding process) or authorization.

The operation of oil and gas pipelines must be authorized by the ANP, except for the distribution of piped gas, which fall within the states' jurisdiction and must be performed by local distribution companies under concession contracts with the relevant states. To obtain an operation authorization, a company must meet the requirements of the Petroleum Law, namely, be a company established under Brazilian law, with headquarters and management in Brazil (*ANP Resolution No. 52/2015*).

The ANP monitors the operation of oil and gas pipelines. Gas transportation tariffs are regulated by the ANP. There are no restrictions on foreign ownership of companies that operate oil and gas pipelines.

Third party access is regulated by the Petroleum Law and the Gas Law. The ANP Resolutions No. 35/2012 and No. 11/2016 regulate the principle of open access. Under this principle, a transporter must allow non-discriminatory access by third parties to its transportation facilities with adequate remuneration calculated using the criteria established by the ANP, taking into account the exclusivity provisions granted to the owner of the facilities (if applicable).

Currently, third-party access rights do not apply to LNG terminals and production offloading pipelines, although this is likely to change if the Bill No. 6407/2013 is approved by the Brazilian Congress.

(Pires et als, 2020, Oil and gas regulation in Brazil: overview - View on <https://uk.practicallaw.thomsonreuters.com>, April 2023).

Today energy market concepts and market situation

Energy Security

Today Brazil energy policy is based on energy security, as a central concept which concentrate on availability of the energy sources at competitive and reasonable price. Brazil has a diverse energy matrix, including a large share of hydroelectric power, biofuels, wind, solar energy, and substantial oil reserves, which contributes to its energy security. As central concept, energy security emphasized the importance of reducing dependence on imported sources as fuels, which Brazil achieves thanks to its vast domestic resources. However, the reliance on hydropower raises concerns regarding vulnerability to droughts, illustrating the trade-offs inherent in energy security considerations.

Sustainability and Environmental Impact

Sustainability is another critical theoretical lens through which Brazil's energy market is analyzed. The country's emphasis on renewables is often cited as a model for sustainable energy development. Theoretical frameworks on sustainability examine the balance between meeting current energy needs and preserving environmental resources for future generations. Brazil faces challenges in this area, particularly concerning the environmental impacts of hydropower projects and oil exploration. Theoretical debates often revolve around finding optimal strategies for mitigating environmental impacts while continuing to exploit these energy sources.

Market Liberalization and Regulation

The theory of market liberalization concept pertains to the degree of government involvement and regulation in the energy sector. Brazil has performed important reforms, moving towards a more liberalized energy market, especially in the oil and gas sector. This includes opening up the market to foreign investors and reducing state control. Also, efforts were made for liberalization on competition, prices, and investment flows. Critics argue that too much liberalization can lead to negative environmental and social outcomes, while proponents believe it encourages efficiency and innovation.

Energy Transition

The concept of the energy transition is particularly relevant to Brazil's energy market. This refers to the shift from fossil fuels to renewable energy sources, driven by technological advancements, environmental concerns, and policy decisions. Brazil's energy transition is characterized by significant investments in wind, solar, and bioenergy, aiming to reduce carbon emissions and

combat climate change. Today energy transition highlights the challenges of managing this shift, including the need for new infrastructure, changes in energy pricing, and social implications.

Renewable Energy Development

Renewable energy development concept apply to Brazil's strategy of leveraging its natural resources for energy production. Theories on innovation diffusion and technology transfer are relevant, as Brazil adopts new renewable technologies and develops domestic expertise. Theoretical discussions also explore the role of government policies, such as incentives and subsidies, in promoting renewable energy. Brazil's approach reflects broader theoretical debates on the most effective ways to stimulate renewable energy development while ensuring economic viability.

Today market situation

According to data distributed by Energy Research Office, the Brazilian internal energy balance in 2022, distributed like in table no. 1 and figure no.1:

Table 1. Brazil Internal Energy Balance 2022

Source	Percentage %
Oil and its derivatives	34.4
Sugar cane biomass	16.4
Natural gas	13.3
Hydraulic energy	11
Wood and vegetable coal	8.7
Mineral coal	5.6
Uranium	1.3
Other renewable energy	8.7
Orther no-renewable energy	0.6

Source: EPE – Energy Research Office.

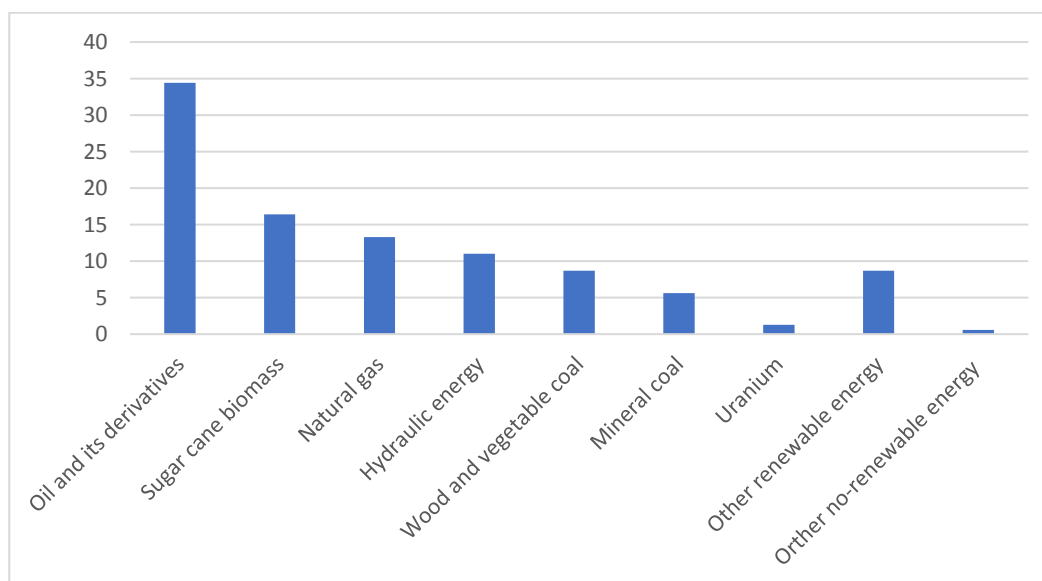


Figure 1. Brazil Internal Energy Balance 2022

Source: EPE – Energy Research Office.

Electricity market

Brazil continues to be the largest energy market in Latin America with opportunities across many subsectors. According to Brazilian Energy Planning Agency's (EPE) and Energy Expansion Plan (PDE) for 2021-2031 the renewable sources will remain a high priority in Brazil's energy market, comprising about 50% of Brazil's energy matrix between 2021 and 2031. In 2020, renewable energy supplied 85% of the electricity sector demand and it is expected to reach 88% by 2030.

Nuclear energy is expected to grow with the Angra 3 power plant's entry into operation, estimated for 2028.

Within the non-renewable sources, oil and gas will continue to play a key role in energy supply for the country. (Note: This energy matrix includes fuels - diesel, gasoline, and ethanol). Total estimated investment in the energy sector through 2031 is \$513 billion for the oil and gas sector and \$101 billion for power generation and transmission.

The electricity sector has an installed capacity of about 173.6 gigawatts (GW), divided among 9,013 power plants, including the following the sources presented in table no.2 and figure no.2:

Table 2. Electricity Generation Installed Capacity

Source	Percentage %
Hydroelectric	62.24
Fossil fuel	16.53
Wind	9.4
Biomass	8.98
Solar	1.78
Nuclear	1.13

Source: EPE – Energy Research Office.

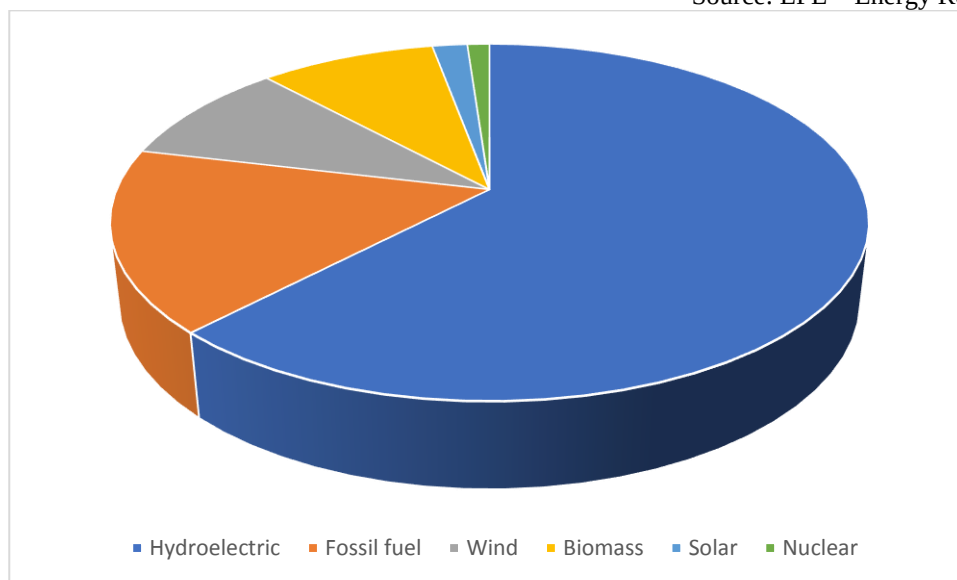


Figure 2. Electricity Generation installed Capacities

After 2004 the electricity market was organized as in table no.3.

Table 3. Electricity market structure after 2004

	Regulated market (ACR)	Free market (ACL)
Type of consumers	Consumers with a capacity below 2 000 kW	Consumers with a capacity starting from 2 000 kW*
Consumers can buy their electricity from	Distribution companies	Generation companies, traders, self-producers and distribution companies
Market mechanism	Regulated auctions with long-term contracts	Bilateral contracts
Price level	Electricity price based on average in regulated auctions, plus cost component for transmission and distribution network	Freely negotiated price for electricity, plus cost component for transmission and distribution network

* Consumers with a capacity starting from 2 000 kW have the possibility to opt-out of the free market, thereby returning to the regulated tariffs applicable in the ACR.

Source: Information provided by ANEEL.

Oil and Gas

As published on www.trade.gov, Brazil Commercial Guide for 2023, Brazil is Latin America's top oil producer. The country owns the largest recoverable ultra-deep oil reserves in the world, with 96.7% of Brazil's oil production produced offshore. The 2021 average oil production was 2.90 million barrels per day. Brazil's deep water **pre-salt fields** accounted for 72.4% of national production. Brazil's 2021-2031 Energy Expansion Plan forecasts that the country's oil production will reach 5.2 million barrels of oil per day by 2031 with the pre-salt fields accounting for nearly 80% of total production. Shallow water and onshore fields are not expected to exceed 7% of total oil output. However, there is an expectation of improvement in the production of these fields due to the Revitalization Program for the Exploration and Production of Onshore Oil and Natural Gas Areas (REATE 2020) and the Revitalization and Incentive Program for the Production of Maritime Fields (Promar). By 2030, Brazil is expected to become the world's fifth largest crude oil exporter.

Brazil's 2021 natural gas (NG) production amounted to 134 million cubic meters/day - up 5% from 2020. Associated gas currently represents approximately 80% of Brazil's NG production, which is expected to reach its peak production of 183 million m³/day by 2028. The actual NG supply in 2021 ended up at 51.49 million m³/day (considering losses, gas reinjection, burn, and E&P consumption). NG domestic production represented 53% of Brazil's supply, while imports from Bolivia reached 20%, followed by LNG imports at 26%. The U.S. was the largest LNG exporter to Brazil in 2021 supplying 22.5 million m³. Common challenges facing the Brazilian gas market include high CO₂ content, long distances from the offshore gas fields to the coast, limited gas pipeline infrastructure, and the need to boost domestic demand.

Significant energy reforms, frequent oil field finds, and the opening of oil bidding rounds have attracted International Oil Companies (IOCs) from around the world. IOCs have acquired oil field concessions, gas pipeline networks, and are developing liquified natural gas (LNG) terminals.

The **EPE 2031 Energy Expansion Plan (PDE)** forecasts that oil and gas exploration and production (E&P) investments will range from \$428 billion to \$474 billion during this period. These figures reflect an evaluation of aggregated investments of all E&P in Brazil, including those from national oil company Petrobras, as announced in its 2022-2026 Strategic Business Plan.

In last decade the Brazilian government has made efforts to attract foreign investment in the oil and gas sector, including regulatory reforms and auction rounds for exploration and production rights. These initiatives aim to bring in capital, technology, and expertise.

Brazil has an opportunity to lead in the energy transition through its biofuel industry. The country is already a major producer of ethanol, which can complement its oil sector and support global decarbonization efforts.

Today oil and gas sector face also some challenges induced by regulatory and fiscal regulation uncertainty during time, which affect investors involvement in sector. The exploration and production of offshore oil reserves, particularly in ecologically sensitive areas, raise significant environmental concerns. There is increasing pressure from environmental groups and society for sustainable practices and minimal ecological impact.

Oil and gas sector is hampered by infrastructure limitations, including transportation and logistics. Developing and enhancing infrastructure is crucial for efficiently managing the production and distribution of oil and gas.

Brazil's economy has faced periods of instability, impacting investment in the oil and gas sector. Economic recovery and stability are vital for sustained growth in the industry.

The global shift towards renewable energy sources poses a challenge to the long-term demand for oil and gas. Brazil's strong potential in hydro, wind, and solar energy could shift focus and investment away from fossil fuels.

We can say that today Brazil's oil and gas market is at a crossroads, with significant opportunities for growth and development, underscored by the vast pre-salt reserves and increasing production levels. The country's strategic importance in the global oil market is set to rise, provided it can navigate the complex challenges it faces. Addressing regulatory and environmental concerns, investing in infrastructure, and leveraging its biofuel capacity are critical for Brazil to realize its oil and gas potential fully. As the world moves towards a more sustainable energy future, Brazil's oil and gas sector must adapt to remain competitive and relevant in the changing energy landscape.

Nuclear Power

Brazil has a promising civil nuclear energy market. **The EPE 2050 Long-Term Energy Expansion Plan** calls for up to eight additional nuclear power plants, adding 10 GWh of production capacity. Local analysts project investments of approximately \$50 billion in Brazil's nuclear energy sector over the next 30 years. These new investments are expected to include Small Modular Reactor (SMR) developments and increased uranium exploitation to allow for "yellow cake" exports of 1.5 tons per year. The U.S. Department of Energy (DOE) is working with EPE to finalize the scope of an assessment of market opportunities for SMRs and advanced micro reactors in Brazil. Government-owned nuclear power project sponsor **Electronuclear** (ETN) views clusters of SMRs as a viable model for the expansion of Brazil's nuclear power fleet. ETN has established SMR related MOUs with selected SMR developers.

Currently, two nuclear reactors, Angra 1 and 2, account for over 1,900 megawatts (MW) of installed capacity, representing 2% of Brazil's power generation. Construction of a third nuclear power reactor, Angra 3, has resumed.

The EPE 2021-2031 Energy Expansion Plan forecasts one new nuclear power plant of 1,000 MW to be in operation by 2031, however, industry sources are skeptical about this new plant, speculating that SMRs may be more realistic given the short timeframe. (www.trade.gov, 2023-Brazil Commercial Guide)

Renewable Energy

Brazil have been a pioneer in utilizing its abundant water resources, leading to a strong dependence on hydroelectric power. This early focus on hydroelectricity set a foundation for renewable energy, making country one of the world's leaders in clean energy from the outset.

Today, renewable energy landscape has diversified. The country boasts a significant share of its energy coming from renewable sources:

- Hydroelectric Power: Still the backbone, accounting for about 60% of Brazil's electricity generation.
- Wind Energy: Brazil is a regional leader in wind energy, with rapidly expanding wind farms, particularly in the northeast.
- Solar Energy: Solar power is witnessing exponential growth, thanks to favorable climatic conditions and declining costs of solar technology.
- Biomass Energy: Utilizing its vast agricultural resources, Brazil effectively converts biomass into energy, especially sugarcane ethanol.

Although oil and natural gas still play a role in Brazil's energy matrix, the shift towards renewables is evident. The country's commitment to reducing carbon emissions and increasing energy security drives this transformation. Renewable energy's share in the total energy mix has been consistently rising, showcasing the efforts to balance economic growth with environmental sustainability.

Brazil's government has been instrumental in promoting renewable energy through a range of policies and legislative measures like PROINFA program, which aims to increase the share of renewable energy sources other than hydropower. This program provides financial incentives and assures purchase agreements for energy produced from wind, biomass, and small hydroelectric sources.

The Brazilian Development Bank (BNDES) have also a central role in financing renewable energy projects. It offers long-term financing options and lower interest rates for projects that align with the country's renewable energy goals. Additionally, certain tax exemptions and reductions are provided to renewable energy projects to encourage investment and lower the cost barrier.

Wind energy

Brazil has seen significant improvements in wind turbine technology. Modern turbines are more efficient, capable of generating more power even in areas with lower wind speeds.

Recent studies and pilot projects are exploring Brazil's offshore wind potential. These projects aim to leverage long coastline to harness wind energy more effectively.

An advanced monitoring systems are being deployed for real-time data analysis, optimizing wind farm performance and predictive maintenance.

The wind energy sector has experienced significant evolution over the last decade, demonstrating remarkable growth and advancements. From 2007 to 2019, the installed capacity surged from 247 MW to 15,378 MW, in 2021 overpassed 20,000MW, exceeding 25,000 MW in 2023.

In some regions the expansion of the wind energy sector faced local opposition and environment problems.

Solar Energy

Brazil is adopting newer solar panel technologies with higher efficiency rates, maximizing energy capture from its abundant sunlight reaching about 27.39 % panels efficiency. Innovative projects

like floating solar panels on hydroelectric dam reservoirs are being tested, combining solar and hydroelectric power to optimize space and energy production.

New battery storage technologies are implemented to gain more efficiency on storage of the solar energy production.

Here bellow we present the evolution of Brazil solar installed capacities between 2013-2023 according data provided by www.statista.com.

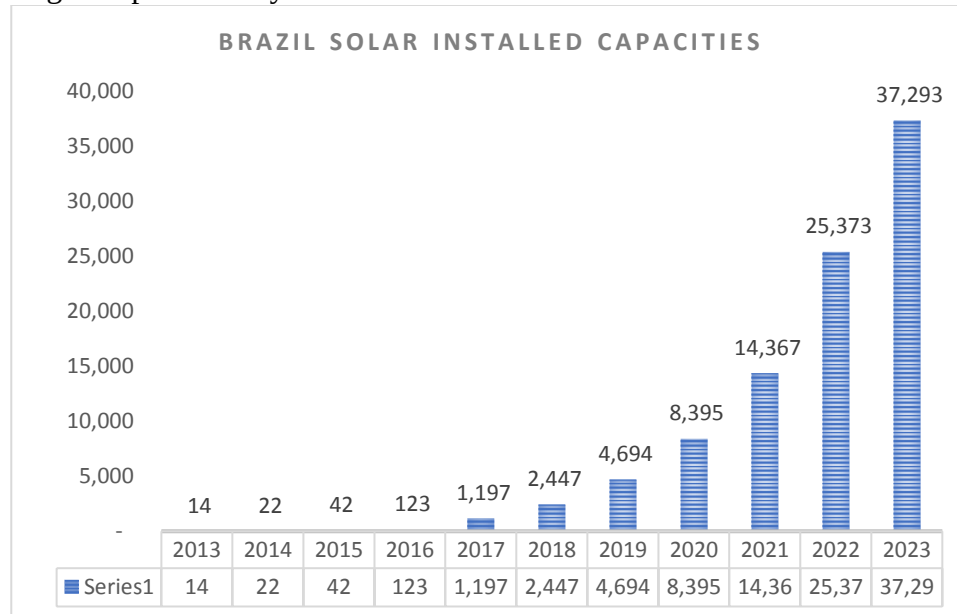


Figure 3

Table 4 Brazil Solar installed capacity evolution 2013-2023

Period	Description	Installed Capacity Milestones	Key Figures and Notes
2013	Solar energy virtually non-existent in Brazil's energy matrix. Installed capacity negligible.	Negligible	
2014	First exclusive auction for solar energy. Start of focused solar energy development.	Under 100 MW	Marked the beginning of Brazil's focused approach towards solar energy development.
2015-2016	Significant additions to solar capacity following auctions. Several large-scale projects commissioned.	A few hundred megawatts	Rapid addition of large-scale solar projects.
2017-2018	Installed solar capacity reaches over 1 GW by end of 2017 and almost doubled in 2018 reaching about 2.5 GW.	Over 1 GW	Substantial increase in both large-scale solar farms and distributed generation systems.
2019	Solar capacity surpasses 4.6 GW. Continued growth in utility-scale projects and distributed generation.	Over 4.6 GW	Driven by favorable regulatory frameworks and decreasing costs of solar technology.

Period	Description	Installed Capacity Milestones	Key Figures and Notes
2020-2023	Maintained growth trajectory despite global challenges. Installed solar capacity reached significant milestones.	Over 8 GW by end of 2020; well over 25 GW by end of 2022 and over 37 GW in 2023	Continued robust growth with estimates suggesting significant increases in installed capacity.

This exponential evolution was encouraged by government regulatory incentives but we should mention also some burdens in sector development represented lack of transparency and uniformity of the licensing procedures regarding the environment.

Bioenergy and Biomass sector

Brazil developed advanced technologies in bioenergy and especially in producing second-generation ethanol from sugarcane bagasse and other agricultural residues;

It is created power plants fired with dual sources like and coal or other traditional fuels in mixture with biomass as an advanced technology for CO2 emission reduction.

Cross-Cutting Technologies

During last decade Brazil has been investing in smart grid technologies to better integrate renewable sources into the national grid, enhancing energy distribution efficiency and reliability.

Parallel on Renewable and Energy Market between Brazil, India and China

Table 5 - Comparative Table regarding Renewable Energy and Energy Market Brazil, India and China

Feature/Market Aspect	Brazil	India	China
Main Energy Sources	Hydropower, bioenergy, wind, solar	Solar, wind, small hydro, biomass	Solar, wind, hydropower, biofuels
Fossil Fuel Production	Significant oil and natural gas production	Limited; relies on imports	World's largest producer and consumer of coal; significant oil and natural gas production
Energy Independence	Working towards self-sufficiency; imports oil and petroleum products	Highly dependent on energy imports, especially for oil and coal	Aims for energy independence; still imports oil but is a net exporter of energy products
Regulatory Framework	Mix of regulated and competitive segments; energy auctions	Supportive policies for renewables; national missions for solar and wind	Centralized government policies; massive subsidies and support for renewables
Grid Interconnection and Infrastructure	Less interconnected with neighboring countries; regionally focused	Challenges with grid connectivity for renewables	Highly interconnected; leading in smart grid technology

Feature/Market Aspect	Brazil	India	China
Market Liberalization and Consumer Choice	Gradually liberalizing; more choices for large consumers	Competitive in renewables sector; varying by state for consumer choice	State-controlled but with increasing market mechanisms
Energy Efficiency and Environmental Regulations	Has energy efficiency programs; growing focus on renewables	Aggressive renewable targets; environmental challenges remain	Strong emphasis on reducing emissions and increasing renewable share
Market Size and Maturity	Substantial but smaller than USA and China	Rapidly growing; among the top global renewable markets	Largest and most mature renewable energy market globally
Renewable Energy Focus	Hydropower and bioenergy; growing wind and solar	Aggressive solar and wind energy expansion; renewable targets	Balanced mix, leading in solar and wind capacity; largest hydropower capacity
Government Support for Renewables	Supportive policies, auctions, incentives for bioenergy	Ambitious government targets, incentives for solar and wind	Ambitious targets, subsidies, R&D support
Challenges	Environmental impact of hydropower; land use for biofuels	Land acquisition, grid integration, financing for renewables	Manufacturing overcapacity; integrating renewables into the grid
Opportunities	Growth in wind and solar; potential in bioenergy expansion	Significant opportunities for solar power due to geography	Global leadership in renewable technology; massive investment in all forms of renewables

Challenges and Opportunities in Renewable Energy

Brazil renewable sources energy production faces limitation due to transmissions and distribution networks whose expansion is lower than sector development. The instability and of legal framework and incentives policies together with high initial investment cost put also a burden sector development due to lack of confidence of the potential investors.

On the other side, speaking on opportunities we should mention first country's huge potential on in wind, solar and biomass sources.

Conclusions

Brazil's energy sector is undergoing a dynamic transformation driven by a growing focus on sustainability, technological advancements, and evolving energy demands. The country's vast renewable energy resources, particularly hydropower and biomass, have positioned it as a global leader in renewable energy integration. However, challenges remain in diversifying the energy mix, addressing infrastructure limitations, and ensuring energy access for all.

Brazil's abundant hydropower potential has historically been the backbone of its electricity generation, accounting for over 60% of the total installed capacity. The expansion of hydropower has been complemented by the growth of biomass-based power generation, which utilizes

sugarcane bagasse, a byproduct of the country's thriving ethanol industry. These renewable energy sources have contributed to Brazil's low carbon footprint in the power sector.

In recent years, Brazil has witnessed a surge in renewable energy diversification, with wind and solar power gaining significant traction. The country's vast wind potential, particularly in the northeastern region, has attracted substantial investments in wind farms, making Brazil one of the world's top wind energy producers. Solar energy has also experienced rapid growth, particularly in distributed generation applications, driven by falling technology costs and government incentives.

Technological advancements have played a crucial role in Brazil's energy transition. The development of smart grid technologies is enabling more efficient and reliable integration of renewable energy sources, while advancements in battery storage technologies are addressing the intermittency challenges associated with renewables. Additionally, research and development efforts in biofuels and other alternative energy sources are paving the way for further diversification of the energy mix.

Brazil's energy demands are evolving, driven by economic growth, urbanization, and changing consumption patterns. The increasing demand for electricity, particularly in urban centers, is putting pressure on the grid and necessitating investments in transmission and distribution infrastructure. Additionally, the growing transportation sector is highlighting the need for cleaner and more sustainable fuels.

Despite the progress made, challenges remain in ensuring energy access for all. While Brazil has made significant strides in electrification, pockets of energy poverty persist, particularly in rural and remote areas. Addressing this issue requires targeted investments in grid expansion and renewable energy microgrids.

In conclusion, Brazil's energy sector is undergoing a remarkable transformation, driven by a commitment to sustainability, technological advancements, and evolving energy demands. The country's vast renewable energy resources, coupled with ongoing technological innovations, position it well for a sustainable energy future. However, challenges remain in diversifying the energy mix, addressing infrastructure limitations, and ensuring energy access for all. Addressing these challenges will require continued policy support, technological innovation, and targeted investments, enabling Brazil to realize its full potential as a global leader in sustainable energy.

References

- Delavechia, R.P.; Ferraz, B.P.; Weiland, R.S.; Silveira, L.; Ramos, M.J.S.; dos Santos, L.L.C.; Bernardon, D.P.; Garcia, R.A.F. Electricity Supply Regulations in South America: A Review of Regulatory Aspects. *Energies* 2023, 16, 915. <https://doi.org/10.3390/en16020915>
- Adilson de Oliveira, 2010, Energy security in South America – Role of Brazil
- Schmidt, G et als, 2021 - Electricity regulation in Brazil: overview view on April 2023 on <https://uk.practicallaw.thomsonreuters.com>
- Saragoça, M., et al. (2023). Oil and gas Regulation- Brazil. In *The Regulation of Energy Markets in Latin America* (pp. 123-145). Springer, Cham.
- Faveret Lampert Advogados. (2021). A general introduction to oil and gas law in Brazil. Lexology. International Trade Administration – Country commercial guides / Brazil energy view on march 2023 on <https://www.trade.gov/country-commercial-guides/brazil-energy>
- International Energy Agency (2023). Latin America Energy Outlook: Overview Brazil.
- International Renewable Energy Agency (2023). Energy Profile: Brazil. Available at: < https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/South%20America/Brazil_South%20America_RE_SP.pdf>.